SPECIFICATION

HIGH SPEED MACHINING TOOL

TECHNICAL FIELD

This invention relates to a component which is excellent in wear resistance, lubricating properties, and fracture resistance, and can be used for high speed machining applications. The invention also relates to a machining tool including the component, and a high speed machining method, especially, a dry cutting method, using the tool.

BACKGROUND ART

In recent years, a high machining speed has been demanded from the viewpoint of increased productivity, and high speed cutting has been desired, for example, in the field of cutting. The range of targets for high speed cutting has been expanded, and there has been a demand for the application of high speed cutting to high hardness materials such as hot forging dies after hardening by heat treatment, and die casting molds.

With conventional cutting methods, cutting oils were used for promoting a lubricating action and cooling a cutting edge, and cutting oils were needed, particularly, in high speed cutting. However, the use of a cutting oil may aggravate a work environment because of a foreign odor, dirt, and greasy fumes. In addition, treatment of a waste oil may pose the problem of environmental pollution, and

cause the corrosion of tools. Thus, dry cutting using no cutting oil is desired and, for this purpose, there is need for the development of a cutting tool having wear resistance, fracture resistance, lubricating properties, and heat resistance. Such a cutting tool should desirably have the above-mentioned characteristics even in a high speed region.

As tools for dry cutting, there are reports on tools having high hardness coatings formed on hard materials for improved durability. Their examples include a high speed tool steel having a Ti-Al-N-C-based coating (see Japanese Patent Application Laid-Open No. 1999-300518), and cemented carbides having coating layers comprising constituents such as TiCN, TiAlN, SiC and Al_2O_3 (see Japanese Patent Application Laid-Open No. 2000-336489 and Japanese Patent Application Laid-Open No. 2001-293611). Methods such as CVD and PVD are used for the formation of these coating layers. An attempt has also been made to perform ion implantation of elements such as Cl and S into tungsten carbide for increased wear resistance (see United States Patent 5,038,645).

With the conventional methods of applying coatings to base materials, however, a coating layer, which comprises a different material from the base material, is deposited, so that peeling is apt to occur between the coating layer and the base material. To enhance adhesion, a method of forming a plurality of layers has been attempted, but involves a complicated process. Furthermore,

even when a coating layer of high hardness is formed, its toughness may be low and, depending on a material to be cut (namely, a work material), fracture may occur, resulting in an insufficient tool life. In addition, when the work material is cut with the high hardness coating layer, swarf deposits on the coating layer, thus presenting the problem that cutting resistance in a high speed region is not fully decreased. With ion implantation of tungsten carbide, wear resistance is improved in a medium speed region (for example, a cutting speed of up to 91 m/minute), but performance obtained is inferior to that of coated tools.

Because of the above-described problems, the cutting speed of the current steels is often set at a maximum of 150 to 200 m/min even with the use of a cutting oil, and is often set at 100/min or less in dry cutting. Thus, dry cutting in a high speed region is difficult.

DISCLOSURE OF THE INVENTION

The present invention has been accomplished in light of the above-described circumstances. It is an object of the invention to provide a machining component, especially, a high speed cutting tool, improved in wear resistance, fracture resistance, lubricating properties, cutting resistance, and heat resistance in a high speed region. It is another object of the invention to provide a high speed machining method, especially a high speed dry cutting method, using the machining component of the present invention.

The present inventors have diligently conducted studies, and found that when a halogen element is added to a surface layer of a machining component, and a workpiece is brought into contact with the so treated machining component at a high speed, characteristics, such as wear resistance and lubricating properties, are improved in accordance with the oxidation promoting effect of the halogen element. This finding has led to the accomplishment of the present invention. According to the present invention, the machining component and the workpiece are subjected to friction at a high speed to cause an interface reaction, whereby the surface of the machining component can be modified to improve wear characteristics. Thus, if the modified surface is worn, a high speed treatment is performed, as appropriate, whereby the modified surface can be regenerated. The use of the machining tool according to the present invention, because of its excellent lubricating properties, enables high speed machining without using a lubricating oil.

The above advantages of the present invention are presumed to be ascribed to a self-lubricating layer containing a Ti oxide phase and/or a Ti-containing compound oxide phase (however, the valence of Ti is greater than 2, but less than 4). The present invention is also characterized in that the self-lubricating film can be formed and regenerated in process during a machining process in a high speed region.

That is, the gist of the present invention lies in a

high speed machining component having a hard material as a base material, and containing at least one element selected from the group consisting of fluorine, chlorine, bromine and iodine, the concentration of the element being in the range of 0.2 mol% to 10 mol% within 1 μm from the surface of the base material. The gist of the present invention also lies in such a high speed machining component that if the high speed machining component has a coating layer containing Ti and C and/or N on the outside of the base material, the high speed machining component contains at least one element selected from the group consisting of fluorine, chlorine, bromine and iodine, the concentration of the element being in the range of 0.2 mol% to 10 mol% within 1 μm from the surface of the coating layer. The at least one element selected from the group consisting of fluorine, chlorine, bromine and iodine can be added by ion implantation. The machining component of the present invention is brought into contact with a workpiece at a speed of 150 m/min or higher, whereby the high speed machining component can be produced.

Further, the gist of the present invention also lies in the above high speed machining component treated in such a manner as to be brought into contact with a workpiece at a speed of 150 m/min or higher.

The gist of the present invention also lies in the above high speed machining component further having a self-lubricating film on a surface in contact with the workpiece. The self-lubricating film is formed by bringing the high

speed machining component into contact with the workpiece at a speed of 150 m/min or higher. A material containing Ti on a surface layer is named as the workpiece used for formation of the self-lubricating film. The self-lubricating film contains a Ti oxide and/or a Ti-containing compound oxide, the average valence of Ti in the oxide and/or the compound oxide is greater than 2, but less than 4, and if the amount of Ti in the self-lubricating film is calculated as TiO_2, the mass ratio expressed as (mass of the calculated TiO_2/mass of the self-lubricating film) is 5% or more.

The gist of the present invention also lies in a high speed machining method using the above-mentioned machining component. It also lies in a high speed cutting tool including the above machining component. With the high speed cutting tool of the present invention, the wear width V_B of a tool flank after cutting is performed under conditions including a depth of cut of 1.0 mm, a feed rate of 0.1 mm/rev, a cutting speed of 400 m/min, and a cutting length of 500 m can be set at 70 μm or less. Moreover, cutting can be carried out at a cutting speed of 150 m/min or higher without the use of a cutting oil.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a model drawing of a cutting step.

Fig. 2 shows the cutting speed dependence of a cutting resistance resultant force in connection with an ion-implanted P10 tool, a TiN-coated P10 tool, and an

untreated P30 tool.

Fig. 3 shows the cutting speed dependence of a feed force in connection with the ion-implanted P10 tool, the TiN-coated P10 tool, and the untreated P30 tool.

Fig. 4 shows the cutting speed dependence of a coefficient of friction in connection with the ion-implanted P10 tool.

Fig. 5 shows the results of a wear test of the ion-implanted P10 tool.

Fig. 6 shows the results of observation of sections of the ion-implanted P10 tool used in cutting of a Ti-deoxidized steel.

Figs. 7(a) to 7(d) show the results of elemental analysis, by XMA, of sections of the ion-implanted P10 tool used in cutting of the Ti-deoxidized steel.

Fig. 8 shows the results of XPS which measured the surfaces of a TiN-coated tool (upper) and an ion-implanted TiN-coated tool (lower) after cutting.

Fig. 9 shows the results of selected area electron diffraction performed at 4 locations of the surface layer of an ion-implanted TiN-coated tool after cutting.

Fig. 10 shows the results of a cutting test conducted on a TiCN-coated tool implanted with ions and a TiCN-coated tool not implanted with ions.

Fig. 11 shows a tool flank wear width after cutting with the use of an ion-implanted TiCN-coated tool. A cutting speed was set at 500 m/min, and a cutting length was set at 500 m or 1,000 m.

Fig. 12 shows sectional views of flank wear states after cutting under the conditions of Fig. 11.

Fig. 13 shows the results of observation of a flank and a tool section (inset) after a cutting test performed in connection with an ion-implanted TiCN-coated tool, with a Ti-deoxidized steel as a work material. The observation of the flank was made by a laser microscope, while the observation of the tool section was carried out by an optical microscope. The upper part of the inset corresponds to a region of 26 mm (long) × 60 mm (wide), and the lower part of the inset corresponds to 80 μm (long) × 100 μm (wide).

Fig. 14 shows the results of observation of a flank and a tool section (inset) after a cutting test performed in connection with an ion-unimplanted TiCN-coated tool, with an Al-deoxidized steel as a work material. The observation of the flank was made by a laser microscope, while the observation of the tool section was carried out by an optical microscope. The upper part of the inset corresponds to a region of 26 mm (long) × 60 mm (wide), and the lower part of the inset corresponds to 80 μm (long) × 100 μm (wide).

DETAILED DESCRIPTION

Hereinbelow, the present invention will be described in detail.

The base material of the high speed machining component according to the present invention can be

selected, as appropriate, in accordance with the material for a workpiece and the shape of the workpiece after machining, and is preferably a hard material. The hard material includes cemented carbide tool materials, ceramics, and ultra-high pressure sintered compacts defined under JIS B 4053, and refer to sintered materials harder than metallic materials produced by the melting method. For example, there can be used alloy tool steels, carbon tool steels, high speed tool steels, powdery high speed tool steels, cemented carbides, cermets, ceramics, forging die steels, alloy tool steels for hot dies, alloy tool steels for cold dies, bearing steels, stainless steels, heat resisting steels, aluminum and its alloys, titanium and its alloys, molybdenum and its alloys, and tungsten and its alloys.

The base material may be coated, or need not be coated. The material for the coating layer is preferably a high hardness material such as a material containing Ti and C and/or N. For example, TiC, TiN, TiCN and TiAlCN are named. In any of these materials, part of Ti may be substituted by other metallic element. Moreover, a plurality of coating layers may be stacked.

If the base material is not coated, at least one element selected from the group consisting of fluorine, chlorine, bromine and iodine is added to a surface layer within 10 μm, preferably within 5 μm, more preferably within 1 μm, from the surface of the base material. If the base material is coated, at least one element selected from

the group consisting of fluorine, chlorine, bromine and iodine is added to a surface layer within 10 μm, preferably within 5 μm, more preferably within 1 μm, from the surface of the coating layer. This element may extend to the base material, without being confined in the coating layer. If the region where the element exists is too thin, durability deteriorates, but if it is too thick, the step of implanting the element is complicated.

The concentration of the fluorine, chlorine, bromine and iodine is 0.2 mol% or higher, preferably 0.5 mol% or higher, more preferably 1 mol% or higher, but 20 mol% or lower, preferably 10 mol% or lower, more preferably 8 mol% or lower. If the concentration is too low, lubricating properties are difficult to improve. If the concentration is too high, the crystal structure of the base material and/or the coating layer may be damaged. The concentration of the element within x μm refers to the maximum element concentration in the range of the depth 0 - x μm when the distribution of the element concentration in the depth direction was measured by XPS, and the element concentration was plotted against the depth.

Ion implantation is named as the method of adding the fluorine, chlorine, bromine and iodine. Various publicly known apparatuses and conditions can be used in ion implantation, and the surface concentration and energy of ion implantation can be selected, depending on the base material and/or the coating layer, in order to fulfill the above-mentioned surface layer concentration. For example,

the surface concentration is 1×10^{15} ions/cm^2 or higher, preferably 1×10^{16} ions/cm^2 or higher, but 1×10^{18} ions/cm^2 or lower, preferably 5×10^{17} ions/cm^2 or lower. Acceleration energy can be set al 20 keV or more, preferably 30 keV or more, but 500 keV or less, preferably 200 keV or less.

An element other than those described above can be used instead of those elements or in combination with those elements, if this element is an element which is incorporated into the surface layer of the machining component in a state where the element can contribute as an oxidizing agent during the machining step.

The base material may further contain Ti. The form of Ti is not limited, but its examples are titanium carbide, metallic Ti, titanium oxide, and titanium nitride. It suffices that these Ti compounds are present at least in the surface layer of the base material, and no restrictions are imposed on the Ti concentration, as long as it exerts no influence on the characteristics of the base material. If the base material is a cemented carbide, for example, the Ti concentration can be set at 0.2 mol% or higher, preferably 1.0 mol% or higher, but 30 mol% or lower, preferably 15 mol% or lower.

If the machining component of the present invention does not have the Ti-containing coating layer, it is preferred for the base material to contain Ti. In this case, Ti can be rendered existent at the above concentration in the surface layer ranging 20 μm, preferably 10 μm, more preferably 1 μm, from the surface of

the base material. If the Ti concentration is too low, improvements in characteristics, such as wear resistance, lubricating properties and fracture resistance, may be insufficient. If the Ti concentration is too high, the characteristics of the base material, such as hardness and strength, may be impaired. However, Ti may be supplied from the outside by a method, such as the use of a workpiece containing Ti. The Ti concentration in the surface layer ranging y μm from the surface refers to the average Ti concentration in the region within y μm from the surface.

If the machining component has the coating layer, the Ti concentration is 0.2 mol% or higher, preferably 1.0 mol% or higher, but 80 mol% or lower, preferably 60 mol% or lower, more preferably 30 mol% or lower, even more preferably 15 mol% or lower, in the surface layer ranging 20 μm, preferably 10 μm, more preferably 1 μm, from the surface of the component. The region where Ti is present at the above concentration may be the Ti-containing coating layer.

Surface treatment for bringing the machining component, which incorporates at least one element selected from the group consisting of fluorine, chlorine, bromine and iodine, into contact with the workpiece at a high speed can improve the characteristics, such as wear resistance, fracture resistance, lubricating properties and heat resistance. The high speed refers to the relative speed of the machining component and the workpiece with respect to

each other being 150 m/min or higher, preferably 200 m/min or higher, more preferably 250 m/min or higher. There is no upper limit on the relative speed, but if it is 1000 m/min or lower, the durability of the machining component is easy to retain. The surface treatment at this high speed can be performed without a lubricating oil.

If the machining component has no Ti-containing coating layer, the base material substantially does not contain Ti, and the workpiece free from Ti is used, it is preferred to bring the machining component into contact with a Ti-containing workpiece beforehand at a high speed (this treatment will be hereinafter referred to as "high speed pretreatment"), thereby improving lubricating properties. If the base material contains Ti, lubricating properties can be improved during the machining process, even without high speed pretreatment. However, not only excellent characteristics can be obtained, beginning at a time immediately after the start of use of the machining component, but can the characteristics such as lubricating properties be also optimized, by carrying out the high speed pretreatment.

If the machining component has the Ti-containing coating layer, the lubricating properties can be improved during the machining process without the high speed pretreatment. By performing the high speed pretreatment, however, not only excellent characteristics can be obtained, beginning at a time immediately after start of use of the machining component, but can the characteristics such as

lubricating properties be also optimized.

There are no restrictions on the workpiece, but if the workpiece is a Ti-containing material such as a Ti-deoxidized steel, there is an advantage for the improvement of the lubricating properties. The presence of Ti in the surface layer of the workpiece, in particular, in advantageous for imparting the lubricating properties in high speed pretreatment and retaining the lubricating properties during the machining process.

If, after lubricating properties are imparted to the machining component, its surface of contact with the workpiece wears and its lubricity declines, the machining component is contacted again with a Ti-containing workpiece at a high speed, whereby lubricating properties can be imparted. From the point of view of supplying Ti to the interface reaction, it is preferred for the Ti-containing workpiece to contain Ti at least in its surface layer.

The reason why the wear resistance and the lubricating properties are improved by the above treatment is not entirely clear. However, it is speculated that a self-lubricating film formed on the surface of contact between the machining component and the workpiece may contribute to these improvements. The self-lubricating film is not a coating layer (for example, the Ti-containing coating layer) adhered from the outside before the machining component is put to machining applications, but refers to a lubricating film formed by a reaction ascribed to the machining component itself. If the machining

component has the coating layer, the self-lubricating film is formed on this coating layer. If the machining component has no coating layer, the self-lubricating film is formed on the base material.

The lubricating film formed by such a process, unlike the conventional coating layer, is advantageous in that if worn, it is regenerated whenever necessary, and shows stable performance. Furthermore, the step of forming the coating layer can be omitted, and the adhesion between the protective layer and the base material can be enhanced. Besides, the self-lubricating film can suppress the deposition of the work material on the surface of the machining component.

The thickness of the self-lubricating film is not limited as long as it enables the effects of the present invention to be exhibited, but the thickness is, for example, 0.05 μm or more, but 10 μm or less.

The constituent of the self-lubricating film is not limited, as long as it imparts wear resistance, lubricating properties, etc. However, if it can undergo shearing deformation in accordance with a contact pressure exerted, lubricating properties can be improved. Thus, the constituent having such deformability is preferred. Examples of such a constituent are Ti oxides represented by TiO_x ($1<x<2$), various Mo oxides, W oxides, and Nb oxides. As the Ti oxide phase, a Magneli phase represented by Ti_nO_{2n-1} (n: integer) is named. A compound oxide containing one or more elements selected from the group consisting of

Ti, Mo, W and Nb is also named. The compound oxide may contain Si and/or Mn, and may, for example, be $MnTiO_3$. The self-lubricating film may contain only one of the above phases, and may contain a plurality of the phases.

Ti of the self-lubricating film may be supplied from the machining component of the present invention, or may be supplied from the work material. If the machining component has the coating layer, Ti can be supplied from the coating layer. If the machining component has no coating layer, Ti can be supplied from the base material.

If the Ti oxide and/or the Ti compound oxide is contained in the self-lubricating film, the average valence of Ti can be greater than 2, but less than 4. If the machining component has no Ti-containing coating layer, the proportion, in the self-lubricating film, of the amount of Ti in the self-lubricating film calculated as the mass of TiO_2 (hereinafter referred to as the calculated TiO_2 mass), namely, the following proportion

calculated TiO_2 mass/ mass of the self-lubricating film × 100 (%)

can be set at 5% or more, preferably 10% or more. If the machining component has the Ti-containing coating layer, the proportion of the calculated TiO_2 mass can be 10% or more, preferably 20% or more, more preferably 40% or more. There is no upper limit on the calculated TiO_2 mass, and the self-lubricating film may be composed of a Ti compound alone. However, the proportion of the calculated TiO_2 mass is often 90% or less, for example, 80% or less, partly

because an ingredient derived from the work material may get in.

Herein, the value obtained as in Example 3 is used as the mass of the self-lubricating film. That is, W, Si, Mn, Al and Ti are measured by XPS, the sum of their masses is calculated on the assumption that they are present as WC, SiO_2, MnO, Al_2O_3 and TiO_2, respectively, and the total value is taken as the mass of the self-lubricating film. The calculated TiO_2 mass refers to the mass of TiO_2 when all of Ti is assumed to be present as TiO_2.

The mechanism by which the self-lubricating film is formed by friction at a high speed is not necessarily clear. However, there may be the following situation: In an environment in which a high pressure load is imposed on the surface layer of the base material, for example, the halogen element in the base material is reduced into monovalent negative ions. In accordance with this reduction, Ti is oxidized, with the result that the aforementioned Ti intermediate oxide lay is formed.

The high speed machining in the present invention refers to machining at a relative speed, between the machining component and the workpiece, of 150 m/min or higher, preferably 200 m/min or higher, more preferably 250 m/min or higher. If the machining component of the present invention is used, dry machining (for example, dry cutting) can be performed without the use of a lubricating oil.

The high speed machining component of the present invention can be used for any instrument, if it is applied

to a site where friction occurs upon contact between the machining component and the workpiece at a high speed. For example, the machining component can be used for cutting tools such as a drill, a milling cutter, a shaving cutter, a hob and an end mill, various molds such as hot forging dies and cold forging dies, and sliding components. If the machining component is used for a cutting tool, the durability of the cutting tool can be improved to extend its life, and its machining accuracy can also be improved.

With the cutting tool of the present invention, the self-lubricating film is formed on the tool flank, so that wear is suppressed. The replacement or regrinding of the cutting tool is usually performed at a time when the flank wear width V_B of the tool reaches 200 to 300 μm, and V_B serves as a good indicator of the degree of wear. With the cutting tool of the present invention, the wear width when dry cutting is performed under the conditions, a depth of cut of 1.0 mm, a feed rate of 0.1 mm/rev, a cutting speed of 400 m/min, and a cutting length of 500 m, can be set at 70 μm or less, preferably 60 μm or less. In connection with the wear width V_B μm after dry cutting is performed under the conditions, a cutting speed of V m/min, and a cutting length of 500 m, the tool of the present invention can fulfill the conditions:

$$V_B \leq V_{B0} + 0.06375 \cdot V$$

where V is 100 m/min or more, but 500 m/min or less, and V_{B0} is 30 μm. As noted here, the wear width V_B is suppressed even at the high cutting speed V, so that the cutting tool

can be rendered long-lived. The dry cutting conditions for the above-mentioned measurement of the wear width are as described in Examples 1 and 5.

Examples

The present invention will be described in greater detail by the following Examples, but the present invention is in no way restricted by these Examples.

<Work material>

Work materials used in the Examples are an Al-deoxidized steel and a Ti-deoxidized steel. These steels were prepared by melt-forming a steel of the S45C composition by a 100 kg high frequency induction furnace, deoxidizing the product with Ti and Al when dividedly pouring it for 50 kg steel ingots, hot rolling the steel ingots to ϕ75 mm, and normalizing the hot rolled plates. The chemical compositions of the resulting steels are as shown in Table 1. The use of Ti for deoxidation is found to increase the Ti concentration in the steel material.

Table 1 Chemical analysis values of the work materials (mass %)

Type of steel	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	S-Al	T-N	Ti	O
Ti-deoxidized steel	0.44	0.34	0.80	0.002	0.001	<.01	<.01	<.01	<.01	<.002	0.0009	0.0100	0.0011
Al-deoxidized steel	0.45	0.35	0.80	0.003	<.001	<.01	<.01	<.01	<.01	0.021	0.0008	0.0005	0.0006

<Preparation of cutting tool>

An untreated P10 type-corresponding tool (composition: WC-TiC (TaC) 30%-Co 10%, Sumitomo Electric Industries, Ltd., shape: TNUN331 (triangular tip), model: ST10P), a TiN-coated P10 type-corresponding tool (P10 type-corresponding tool multi-layer-coated with TiCN, Al_2O_3, and TiN in this order, MITSUBISHI MATERIALS CORP., shape: comparable to P10 tool, model: UE6005), and a TiCN-coated P10 type-corresponding tool (P10 type-corresponding tool vapor-deposited alternately with ultra-thin films of TiC and ultra-thin films of TiN, Sumitomo Electric Industries, Ltd., shape: TNUN331, model: K29J) were ion-implanted using chlorine. The conditions for the ion implantation were 100 keV and 1×10^{17} ions/cm^2 for all of the tools. The ion implantation was performed only for the rake face. The maximum chlorine concentration measured by XPS was 5 mol%.

The Ti concentration of the uncoated P10 type-corresponding tool was 23 mol%, while the surface Ti concentration of the coated tools was 50 mol%. The thicknesses of the coating films were 1 to 5 μm.

<Example 1> Cutting resistance test of the uncoated tool

The ion-implanted P10 tool, and an ion-unimplanted TiN-coated P10 tool were subjected to a dry cutting test in a low speed to a high speed region to measure cutting resistance. As a control, a P30 tool (an untreated product which has not been ion-implanted or coated, composition WC-TiC (TaC) 8%-Co 10%, MITSUBISHI MATERIALS CORP., shape:

comparable to P10 tool, model: UT20T) was also subjected to the test. The cutting conditions were as follows:

Depth of cut Dc: 1.0 mm

Feed rate f: 0.1 mm/rev

Work materials: Al-deoxidized steel and Ti-deoxidized steel of Table 1

Cutting speed: Increased from 10 m/min to 300 m/min with the same tool

A force exerted on the tool during cutting, and the formation of a self-lubricating film are shown in Fig. 1.

Fig. 2 shows the cutting speed dependence of a cutting resistance resultant force (R). All of the tools had maximum values in the medium speed region (40 to 100 m/min), and the values decreased as the speed became high. However, the ion-implanted tool showed a characteristic behavior in the high speed region.

At 20 to 50 m/min, it is seen that the ion-implanted tool had a greater cutting resistance resultant force than that of the TiN-coated tool, and the rate of an increase in the resistance resultant force in accordance with the increase in the speed was also greater. As the cutting speed was further increased, however, the ion-implanted tool showed lower R. That is, it is found that the results in the high speed region are different from the results in the medium speed region; in the high speed region, the ion-implanted tool obtains higher lubricating properties. For example, the value of R in the ion-implanted tool at 300 m/min decreased from the value of the TiN-coated tool by

12%.

A comparison between the P30 type-corresponding tool and the tool of the present invention shows that an advantageous effect is obtained in the medium speed range as well. At the cutting speed of 50 m/min or higher, R decreased by about 20% in the tool of the present invention as compared with the P30 type tool.

A similar phenomenon was observed with a feed force (Fs; Fig. 3). At a cutting speed of 300 m/min, the tool of the present invention was able to reduce Fs by 10 to 15% in comparison with the TiN-coated tool. Even compared with the P30 type-corresponding tool, the tool of the present invention was able to reduce Fs by about 25% at a cutting speed of 50 m/min or higher. As noted from these results, according to the present invention, the machining force can be decreased markedly by implanting ions into the base material, without applying a coating.

Moreover, regarding the friction coefficient on the tool-swarf contact surface (μ; Fig. 4) geometrically calculated from the principal force (Fc) and the feed force (Fs), the ion-implanted tool showed excellent characteristics in the high speed region. In connection with the friction coefficient at 300 m/min, for example, the value of the ion-implanted tool decreased by 10% in comparison with the TiN-coated tool, showing that the ion-implanted tool is excellent in wear resistance. Compared with the P30 type-corresponding tool, the ion-implanted tool showed a decrease of about 10% in the friction

coefficient at a cutting speed of 50 m/min or higher. As seen from these results, the friction coefficient on the tool-cutting contact surface can also be decreased by the present invention.

In the cutting test of the ion-implanted tool, the two types of work materials with different Ti concentrations (i.e., Ti-deoxidized steel and Al-deoxidized steel) were used, and higher performance was obtained for the work material with a higher Ti content (Ti-deoxidized steel). These results show that if Ti is present in the work material, the lubricating properties of the cutting tool of the present invention are further improved.

<Example 2> Wear characteristics of ion-implanted uncoated tool

A wear test, by dry cutting, of the P10 ion-implanted tool was conducted. The conditions for the test are as follows:

Cutting speed V: 50 - 250 m/min

Cutting length: 500 m

(Cutting time depends on the cutting speed; for example, it is 10 minutes at V = 50 m/min, and 2 minutes at V = 250 m/min)

Work materials: Al-deoxidized steel and Ti-deoxidized steel described above

Other conditions were the same as those in Example 1.

The rake face wear depth (k_T) and flank wear width (V_B) of the tool after the test were measured to evaluate wear (Fig. 5). As shown in Fig. 5, when the Ti-deoxidized

steel is used as the work material, k_T and V_B are smaller, and thus wear characteristics are improved.

<Example 3> Analysis of self-lubricating film of ion-implanted uncoated tool

In connection with the ion-implanted P10 tool used in the same cutting as in Example 1, the resulting self-lubricating film was observed with an optical microscope (Fig. 6). As a result, the formation of the film on the surface of contact with the work material was noted.

The composition of the film was measured by XAM (Figs. 7(a) to 7(d)). As shown in Figs. 7(a) to 7(d), Ti-Mn-Si compound oxides are formed in the vicinity of the surface of contact with the work material.

In Figs. 7(a) to 7(d), W, Si, Mn, Al and Ti were measured in the film region, and their masses were calculated on the assumption that they would exist as WC, SiO_2, MnO, Al_2O_3 and TiO_2, respectively, and the sum of these masses was taken as 100%. The values of the mass % obtained for each compound based on this assumption were indicated for the respective elements in Figs. 7(a) to 7(d). In regard to Ti, for example, the mass ratio expressed as

$$TiO_2/(WC+SiO_2+MnO+Al_2O_3+TiO_2)\times 100\ (\%)$$

was indicated. Actually, however, W, Si, Mn, Al and Ti can exist in different forms from WC, SiO_2, MnO, Al_2O_3 and TiO_2. The indication ($aSiO_2$-bMnO-$cTiO_2$) in Figs. 7(a) to 7(d) shows that the Si/Mn/Ti molar ratio is roughly a/b/c.

<Example 4> Analysis of self-lubricating film of ion-implanted TiN-coated tool

Cutting was performed in the same manner as in Example 1 with the use of the ion-implanted TiN-coated tool. Then, the elemental analysis of the self-lubricating film was made by XPS (Fig. 8), and the crystal structure was examined by selected area electron diffraction (SAED) (Figs. 9(a) to 9(d)). Fig. 8 also shows the results on an ion-unimplanted TiN-coated tool as a control. The spectra in the upper part and the lower part of Fig. 9 were measured by the same analytical device under the same conditions, so that the peak absolute intensities of both spectra can be compared. On comparison of the peak intensities due to Ti, the ion-implanted tool is found to be higher in the Ti concentration on the surface than the ion-unimplanted tool. In the ion-unimplanted tool, a strong peak due to Fe is observed, suggesting that the work material is deposited on the surface layer. In the ion-implanted tool of the present invention, on the other hand, strong Ti peaks are observed, suggesting that the deposition of the work material is suppressed, and a Ti-containing self-lubricating film is formed.

In Fig. 8, only the peaks of TiO_2 and TiN showed identity. However, the peaks of Ti of Ti oxide and/or compound oxide phases having a Ti valence of more than 2, but less than 4 are presumed to become shoulders on a lower binding energy side than the peak of TiO_2. The presence of these Ti oxide phases is backed up by the electron diffractions of Figs. 9(a) to 9(d).

Figs. 9(a) to 9(d) also show the phases identified

by the diffraction patterns. Ti oxide phases (including a Magneli phase) having a Ti valence of greater than 2, but less than 4 are seen to have been formed. The results of Figs. 9(a) to 9(d) show the formation of a self-lubricating film containing Ti oxide phases.

<Example 5> Cutting test of ion-implanted TiCN-coated tool

In connection with the ion-implanted TiCN-coated P10 tool, cutting was performed under conditions including a depth of cut (Dc) of 1.0 mm, a feed rate (f) of 0.1 mm/rev, and a cutting length of 500 m to investigate wear characteristics (Fig. 10). The aforementioned Al-deoxidized steel and Ti-deoxidized steel were used as work materials. For purposes of comparison, the test was also conducted on an ion-unimplanted TiCN-coated tool.

When ion implantation was not performed, the wear width V_B sharply increased when the cutting speed exceeded 300 m/min, making cutting difficult at 500 m/min. With the ion-implanted tool of the present invention, on the other hand, cutting was possible even at the cutting speed of 500 m/min, showing that wear was suppressed. Particularly when the work material was the Ti-deoxidized steel, the increase in the wear width was slow even at the cutting speed of 300 m/min or higher, and V_B after cutting over a distance of 500 m at the cutting speed of 500 m/min in the high speed region remained to be 57 μm. Even if the replacement of the tool is to be carried out when V_B = 200 μm, it is expected that cutting over 1,700 m or more can be performed.

Fig. 11 shows the relationship between the tool wear

width V_B and the cutting length at a cutting speed of 500 m/min. When the work material was the Al-deoxidized steel, V_B increased nearly proportionately with the increase in the cutting length. With the Ti-deoxidized steel, on the other hand, the increase in V_B was seen to slow when the cutting length exceeded 500 m. A comparison of the amount of increase in V_B between the cutting lengths of 500 m and 1,000 m shows that the value of the Ti-deoxidized steel was only 1/6 of the value of the Al-deoxidized steel.

As a cause of such a difference, a difference in the nature of the self-lubricating film formed on the tool flank is named. The self-lubricating film corresponds to the region described as Belag in Fig. 12. When a Ti-containing material such as a Ti-deoxidized steel is used as the work material, it is speculated that a self-lubricating film containing a Ti-containing oxide phase is formed, and effectively protects the tool flank from rubbing against the machined surface.

In connection with the tool used in the cutting test of Example 5, the surface of the flank was observed with a laser microscope, and a section of the tool was observed with an optical microscope.

Fig. 13 shows the results of observations with a laser microscope (scanning laser microscope, 1LM21W, Lasertec Corp.) and an optical microscope after the above test was performed over a cutting length of 500 m in connection with the ion-implanted TiCN-coated P10 tool, with the Ti-deoxidized steel as a work material. An

oblique surface generated on the surface of the flank reflects a self-lubricating film formed during cutting. A dark, dense area observed in the sectional view is considered to correspond to the self-lubricating film.

Fig. 14 shows the results of observations with the laser microscope and the optical microscope after the above test was performed over a cutting length of 500 m in connection with the ion-unimplanted TiCN-coated P10 tool, with the Al-deoxidized steel as a work material. In Fig. 14, unlike Fig. 13, the formation of a clear self-lubricating film was not observed. These results suggest that the formation of a self-lubricating film is promoted by ion-implanting a halogen and using a Ti-containing work material.

INDUSTRIAL APPLICABILITY

According to the present invention, a high speed machining component excellent in wear resistance and lubricating properties can be obtained by ion-implanting a halogen element into a base material, which is a hard material, and/or a Ti-containing coating layer, and further bringing the so treated product into contact with a workpiece at a high speed. High speed dry cutting can be performed by a cutting tool using this component.